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DASYCLADALEAN GREEN ALGAE AND ASSOCIATED FORAMINIFERS IN MIDDLE TRIASSIC (LOWER AND MIDDLE MUSCHELKALK) CARBONATES OF THE SOUTH-EASTERN GERMANIC BASIN (UPPER SILESIA, POLAND)

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Abstract: Middle Triassic dasycladalean algae occur in limestones and dolstones of the Diplopora Beds in Upper Silesia, a region representing the southern part of the Germanic Basin. The dasycladales assemblage of this area was studied by Kotański at the end of the last century, mostly from dolomitized and weathered material. The relatively well-preserved specimens the authors found in thin sections from undolomitized strata allowed the description and revised taxonomical assignment of the algae. The identified microflora includes: *Diplopora annulatissima* Pia, 1920, *Diplopora annulata* (Schafhäutl, 1853), *Salpingoporella* cf. *krupkaensis* Kotański, 2013, *Physoporella prisca* Pia, 1912, *Physoporella* cf. *pauciforata* (Gümbel, 1872), *Holosporella*? sp. 1, and *Holosporella*? sp. 2. *Diplopora annulatissima* and *Favoporella annulata* Sokač, 1986 are regarded here as two different species. *Oligoporella elegans* Assmann ex Pia, 1931, extensively illustrated and described by Kotański (2013), is considered a junior synonym of *Oligoporella prisca* Pia, 1912, and transferred to the genus *Physoporella* emended by Grgasovic, 1995. Also, some of the dasycladalean algae (*Salpingoporella* cf. *krupkaensis*, *Holosporella*? sp. 1, and *Holosporella*? sp. 2) described here could represent new species, but more well-preserved material is necessary. The algae are accompanied by foraminiferal microfauna, which collectively indicate a late Anisian (Illyrian) age of the strata studied.

Key words: Dasycladales, green algae, benthic foraminifera, Middle Triassic, Muschelkalk, Poland.

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INTRODUCTION

Since the nineteenth century, when the first studies on Triassic calcareous algae were published, especially from the Alpine region (e.g., Schafhäutl, 1953; Gümbel, 1872, 1874; Benecke, 1876; Salomon, 1895), descriptions have been provided also of the "Nulliporae" (i.e., dasycladales) from the Upper Silesian region in the south-eastern Germanic Basin (e.g., Eck, 1862; Gümbel, 1872; Ahlburg, 1906). From the very beginning, the authors emphasized the special kind of preservation of the dasycladaleans from the Upper Silesian region, affected by complete dissolution of the originally aragonitic skeleton, leaving only internal moulds, which are now filled with cement. More recently, papers on the Upper Silesian dasycladaleans were published by Pastwa-Leszczyńska and Śliwiński (1960), Kotański (1979, 1981, 1986, 1994), and Myszkowska (1992). An important monograph dedicated to these algae was published posthumous by Kotański (2013). In this paper, Kotański described and illustrated 21 dasycladalean species, including three new species. The largest part of the material from the above-mentioned studies in Upper Silesia is represented

by internal moulds and collected from dolomitized strata of the so-called "Diplopora Dolomite" or "Diplopora Beds".

In the present paper, the authors describe seven dasycladalean species identified in thin sections from the Diplopora Beds in Upper Silesia, mainly from localities that have never been studied for algae and where the strata are undolomitized. Most of these algae were identified also by Kotański (2013) as weathered material. The aim of the present authors was to study and illustrate these algae in relatively well-preserved specimens and to revise their systematic assignment according to some recent studies (e.g., Grgasović, 1995; Grgasović and Sokač, 2003).

GENERAL SETTING

Palaeogeography

In Middle Triassic times, the semi-closed and tropical Germanic Basin was connected with the southerly located Tethys Ocean through three narrow, submeridional seaways, called the East Carpathian Gate, Silesian-Moravian Gate, and Western Gate (Fig. 1). The gates developed at the tips of the Tethyan rift system and were opening and closing diachronously from the east to west, as the Tethyan spreading center migrated westwards through time (Szulc, 2000). The Upper Silesia study region is located at the northern outlet of the Silesian-Moravian Gate and was bounded to the west by the Bohemian Massif, to the east by the Małopolska Massif, and to the north-east by an archipelago of several cliff-edged Devonian islands.

The sedimentary record in Upper Silesia was controlled in the first place by long-term tectonic evolution of the neighboring gate. The gate opened in the Olenekian, reached its maximal width in the Pelsonian (mid-Anisian), and closed with the Fassanian (early Ladinian). Consequently, the Lower Muschelkalk deposited during the gradual gate opening is ~100 m thick and dominated by open-marine limestones, while the Middle and Upper Muschelkalk formed during progressive tectonic uplift of the area is half the thickness and more dolomitic-siliciclastic (Szulc, 2000; Matysik, 2016). Within this 7-Myr trend, the temporal facies development reflected superimposed third- to fifth-order relative sea-level oscillations, which created an alternation of transgressive and highstand systems tracts (Szulc, 2000; Matysik, 2014, 2016) with internal high-frequency depositional cycles (Matysik, 2019). The spatial facies distribution in each time interval was dictated by the morphology of the Upper Silesian carbonate platform, which dipped to the south-west and thus had shallower and sometimes more restricted facies in the eastern (Kraków-Silesia) area, compared to the western (Opole) district (Wyczółkowski, 1971; Matysik, 2014; Matysik and Surmik, 2016). Local geomorphic lows and highs (Matysik, 2016) as well as synsedimentary block tectonics (Szulc, 1989, 1993; Matysik and Szulc, 2019) modified this simple facies pattern, sometimes producing a mosaic record.

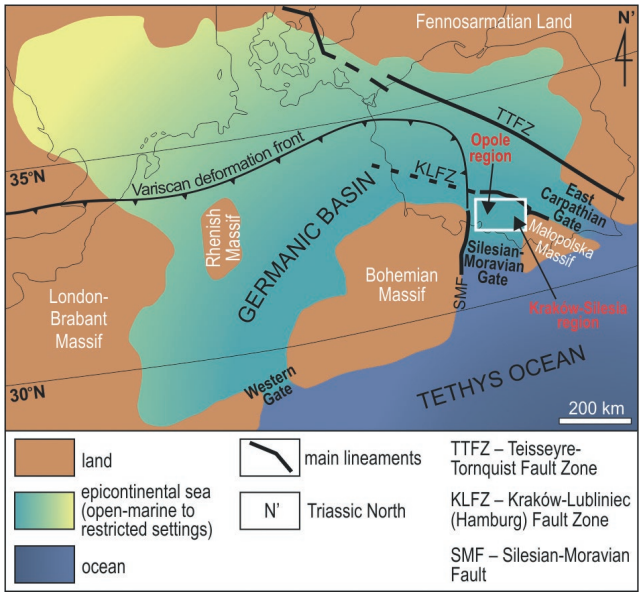


Fig. 1. Palaeogeographic position of the Upper Silesia study region (white rectangle) in the Middle Triassic. Modified from Szulc (2000).

Stratigraphy

The Upper Silesian Muschelkalk is subdivided into nine lithostratigraphic formations (informally called 'beds'; Assmann, 1944; Śliwiński, 1961) that more-or-less correspond to the systems tracts of four third-order transgressive-regressive, disconformity-bounded sequences (Fig. 2; Szulc, 2000). The first Muschelkalk sequence (15 m thick) is largely composed of transgressive ramp tempestites and fair-weather lime muds, directly capped by lagoonal to supratidal dolomitic facies (Lower Gogolin Beds). The second Muschelkalk sequence (40 m thick) starts with a very similar transgressive ramp succession (Upper Gogolin Beds and the lower half of the Olkusz Beds), which evolved with time into a nearly flat carbonate bank with peloid-oncoid-ooid sand shoal complexes and interbedded micrites representing highstand deposits (Górażdże Beds and the upper half of the Olkusz Beds).

The third Muschelkalk sequence (50 m thick) was deposited during the maximum opening of the Silesian-Moravian Gate and is the main storage setting for green algae in the Upper Silesian Muschelkalk. The sequence displays a very complex internal architecture, with peritidal carbonates in the eastern Kraków-Silesia region and open-marine facies in the western Opole region (Fig. 2). The peritidal succession representing a back-barrier area is tripartite. Its lower (transgressive) and upper (regressive) parts comprise lagoonal peloid sands and burrowed muds, intertidal cryptalgal laminites and loferites, and supratidal caliche levels, organized in various configurations into metre-scale cycles (Matysik, 2019). The middle part, corresponding to maximum flooding of the area, is entirely subtidal and dominated by peloid and oncoid sands (Fig. 3A). All these strata are dolomitized and are called "Diplopora Beds" because of ubiquitous diploporacean green algae, which are concentrated particularly in the middle subtidal part of the succession (Fig. 3B). In contrast to the peritidal succession, the open-marine succession, developed in front of the barrier, starts with transgressive tempestites and deeper-platform

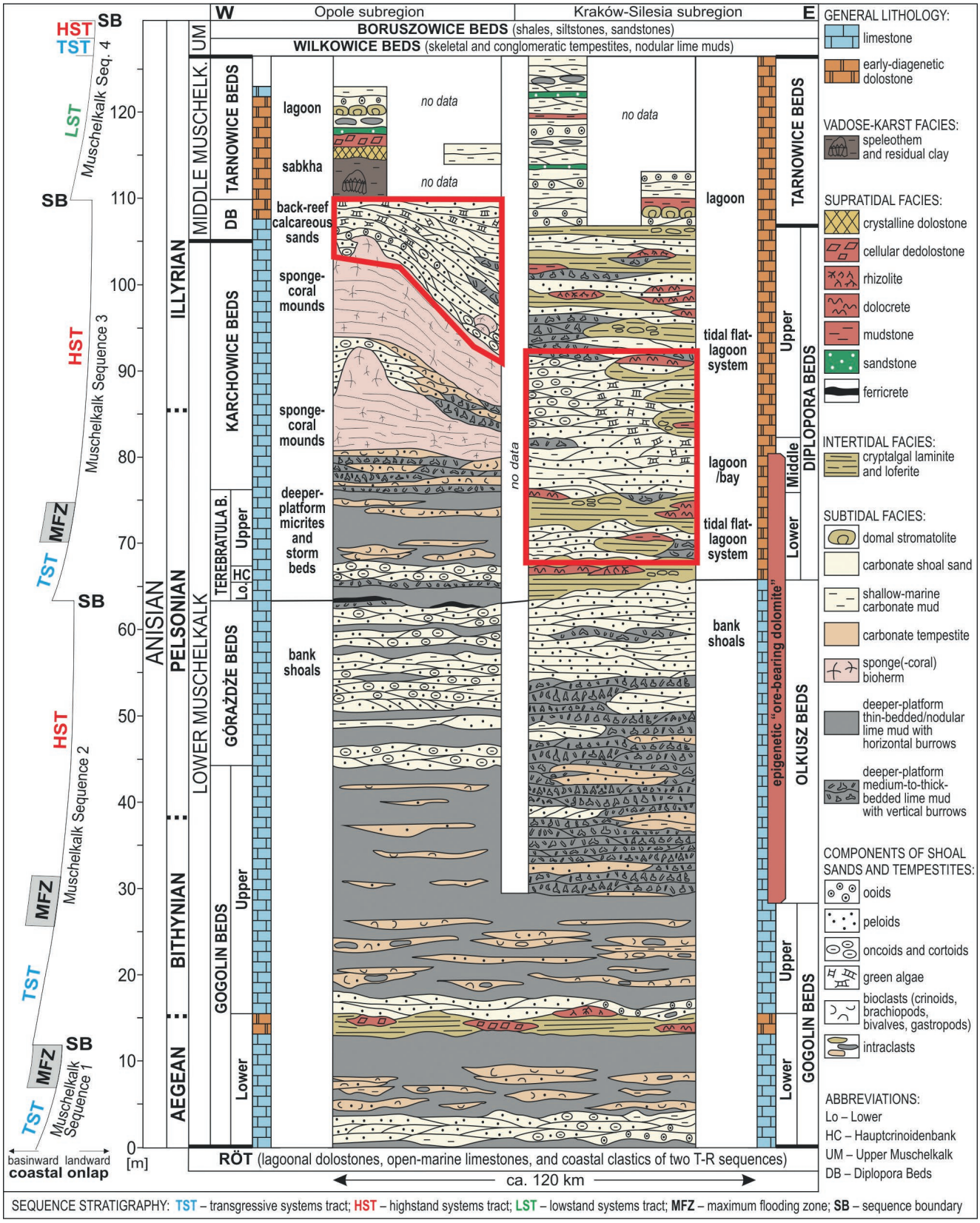
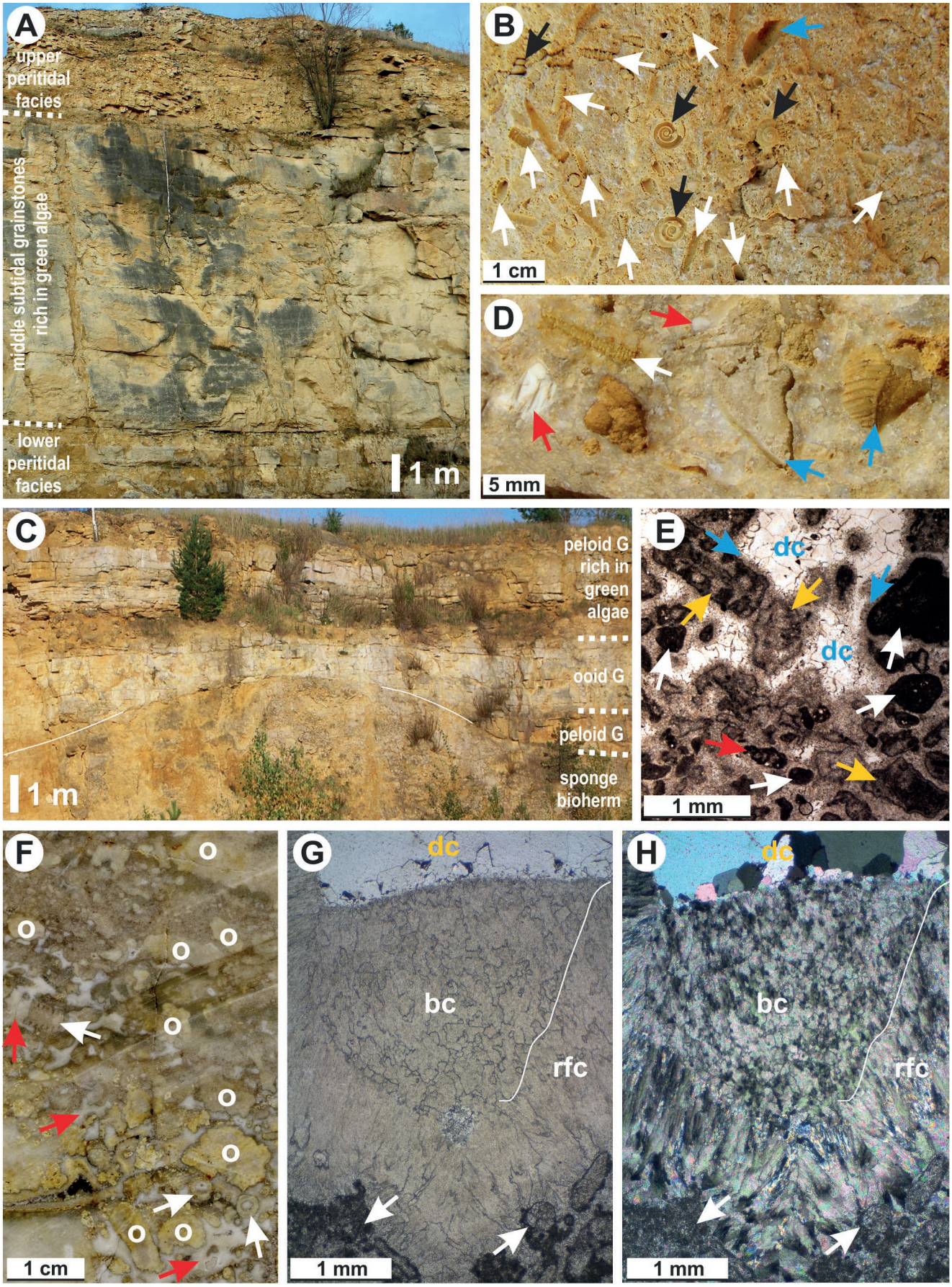


Fig. 2. Generalized stratigraphic section for the Upper Silesian Muschelkalk, showing thickness, overall lithological character, provisional formation names, 3rd-order transgressive-regressive sequences, and algae-rich intervals (red thick outlines). The transition between the eastern Kraków-Silesia region and western Opole region is not recognized because of the lack of outcrops. Note that the algae-bearing interval is slightly older in the Kraków-Silesia region than in the Opole region, on the basis of the sequence stratigraphic correlation. Scheme modified from Matysik (2014), sequence stratigraphy framework after Szulc (2000), supplemented by Matysik (2014), lithostratigraphy after Assmann (1944) and Śliwiński (1961) with later changes by Szulc (2000) and Matysik (2014).


A
upper peritidal facies
middle subtidal grainstones rich in green algae
lower peritidal facies
1 m
B
1 cm
D
5 mm
C
peloid G rich in green algae
ooid G
peloid G
sponge bioherm
1 m
E
dc
dc
1 mm
F
1 cm
G
dc
bc
rfc
1 mm
H
dc
bc
rfc
1 mm

lime muds (Terebratula Beds). They are succeeded by a regressive suite of micritic firmgrounds, bioclastic tempestites, sponge-scleractinian patch reefs, and circumreefal crinoid-peloid sands (Karchowice Beds), shallowing to ooid-peloid sands with abundant green algae (Diplopora Beds; Fig. 3C–E; Matysik, 2010). The latter are generally dolomitized in their upper part, with only few localities from the lower part avoiding dolomitization, which were the main focus of this study (Fig. 3C–H). The barrier separating the peritidal and open-marine domains is unknown due to the lack of outcrops and cores.

The last Muschelkalk sequence is poorly exposed. It comprises restricted dolomitic (Tarnowice Beds), transgressive open-marine (Wilkowice Beds), and regressive siliciclastic (Boruszowice Beds) facies, deposited in a marginal sea (Szulc, 2000).

The sequence stratigraphy framework outlined above is correlated with the Alpine successions using magnetostratigraphy (Nawrocki and Szulc, 2000) and conodont, ammonoid, crinoid, and green algae biostratigraphy (Assmann, 1944; Zawidzka, 1975; Hagdorn and Głuchowski, 1993; Kotański, 1994; Kaim and Niedźwiedzki, 1999; Narkiewicz and Szulc, 2004). Details of the stratigraphy, sedimentology, environmental setting, and ichnology are discussed in numerous articles, particularly in Assmann (1944), Szulc (2000), Matysik (2014, 2016), and Stachacz and Matysik (2020).

MATERIALS AND METHODS

Fieldwork was conducted in 15 large, active and small, inactive quarries, scattered over an area of 120 x 50 km between Opole in the west and Chrzanów in the east (for the GPS coordinates of each outcrop, see the Appendix). Each outcrop was subjected to a search for fossil algae and associated bioclasts in the walls and loose blocks. The most interesting sections were also measured bed by bed. Around 50 samples were collected and slabbed for further palaeontological and facies analyses. Petrographic observations of 61 thin sections were focused on identifying fossils and characterizing their host sediment. All thin sections collected are housed in the Institute of Geological Sciences, Jagiellonian University in Kraków.

RESULTS

Environmental context for the algae and their preservation

The algae studied generally occur in grainstones, where they are the main rock-forming component or the accessory component of peloids, ooids, oncoids, and/or other bioclasts, including bivalves, gastropods, crinoids, small benthic foraminifers, and ostracods (Fig. 3). However, depositional and diagenetic aspects of the sediments vary across Upper Silesia, affecting the preservation of the algae.

In the eastern Kraków-Silesia region (peritidal back-barrier facies), the sediments are densely packed and partly to completely dolomitized (Matysik, 2014), which hinders the detailed taxonomical identification of the algae (Fig. 3B). Only rare specimens are better preserved. This kind of material prevails in the articles published so far (Pastwa-Leszczyńska and Śliwiński, 1960; Kotański, 1979, 1981, 1986, 1994, 2013; Myszkowska, 1992). The localities studied include Nowa Wioska, Ząbkowice, Libiąż, Stare Gliny, and Przełajka.

In contrast, in the western Opole region (open-marine facies), the sediments are less densely packed and often volumetrically dominated by various (mainly early marine) aragonite and calcite cements, which most likely inhibited the downward percolation of dolomitizing fluids from the overlying Tarnowice Beds. In most localities, including Tarnów Opolski, Kamień Śląski, and Strzelce Opolskie, the grains are coated with a <0.2-mm-thick isopachous rim of fibrous cement, with the remaining interparticle pore space filled by drusy calcite or calcite spar (Fig. 3E). Farska Kolonia is unique, because the components are often very loosely organized and enclosed by an isopachous rim of radiaxial-fibrous cement, 0.2–2 mm thick, filling most interparticle pores. In scattered larger pores (which could be growth-framework cavities), this cement is locally post-dated by botryoidal cement, with the remaining pore space occluded with drusy calcite (Fig. 3F–H). The loose character of sediments, lack of interparticle micrite, and variety of early-marine cements collectively point to a turbulent, mud-free habitat for the algae and very rapid cementation of the sediment, almost at the seafloor.

Fig. 3. Selected sedimentological aspects of the algae-rich Diplopora Beds in the Kraków-Silesia (A, B) and Opole (C–H) regions. **A.** Representative outcrop view of dolomitized Diplopora Beds, with lower and upper peritidal facies separated by thick-bedded, lagoonal, algae-rich grainstones. Nowa Wioska. **B.** Detail of A, showing green algae (white arrows), gastropods (black arrows), and bivalves (blue arrow), embedded in peloid grainstone. **C.** Outcrop view of sponge bioherm (Karchowice Beds), overlain by undolomitized Diplopora Beds, shallowing from peloid grainstone, to ooid grainstone, to peloid grainstone with abundant green algae. Kamień Śląski. **D.** Bedding plane view of ooid-peloid grainstone with bivalves (blue arrows), crinoids (red arrows), and green alga fragment (white arrow). The sediment comes from Tarnów Opolski, but corresponds to the level of pure ooid grainstone shown in C. **E.** Plane-polarized view of C, showing undetermined green algae (yellow arrows), peloids (white arrows), and small benthic foraminifer (red arrows), all enclosed by thin isopachous rim of fibrous cement (blue arrows). The remaining interparticle pore space in the upper half of the photo is filled with drusy calcite (dc). **F.** Vertically oriented slab of oncoid (o) grainstone with scattered green algae (white arrows) and various cements filling interparticle pores (red arrows). Farska Kolonia. **G, H.** Plane- and cross-polarized views of larger interparticle pore, lined with radiaxial-fibrous cement (rfc), post-dated by botryoidal cement with fibres growing perpendicular to the photo (bc), and occluded with drusy calcite (dc). Farska Kolonia.

Systematics

Order DASYCLADALES Pascher, 1931
Family DIPLOPOREAE (Pia, 1920) Deloffre, 1988
Genus *Diplopora* Schafhäutl, 1863, emend. Güvenç, 1979
Diplopora annulatissima Pia, 1920
Fig. 4A–I

1920 *Diplopora annulatissima* nov. spec. – Pia, p. 67, text-fig. 15, plate 4, figs 11–16.

2000 *Kantia monregalensis* Baretti, 1919 – Granier and Grgasović, p. 85, with extended synonymy.

2013 *Diplopora annulatissima* Pia, 1920 – Kotański, p. 96, text-fig. 23, plate 26–30.

Remarks: *Diplopora annulatissima* is one of the most frequent dasycladalean species in the region studied; this was also noted by Kotański (2013, p. 97). It is characterized by a single whorl of laterals within a ring (Fig. 4A–G). The laterals have a trichophorous to acrophorous shape (Fig. 4H, I), except for the specimen in Fig. 4C, which shows a possible distal enlargement, characteristic of *Favoporella annulata* Sokač, 1968. The tangential sections (Fig. 4F, G) show four laterals in a tuft.

Dimensions (in mm):

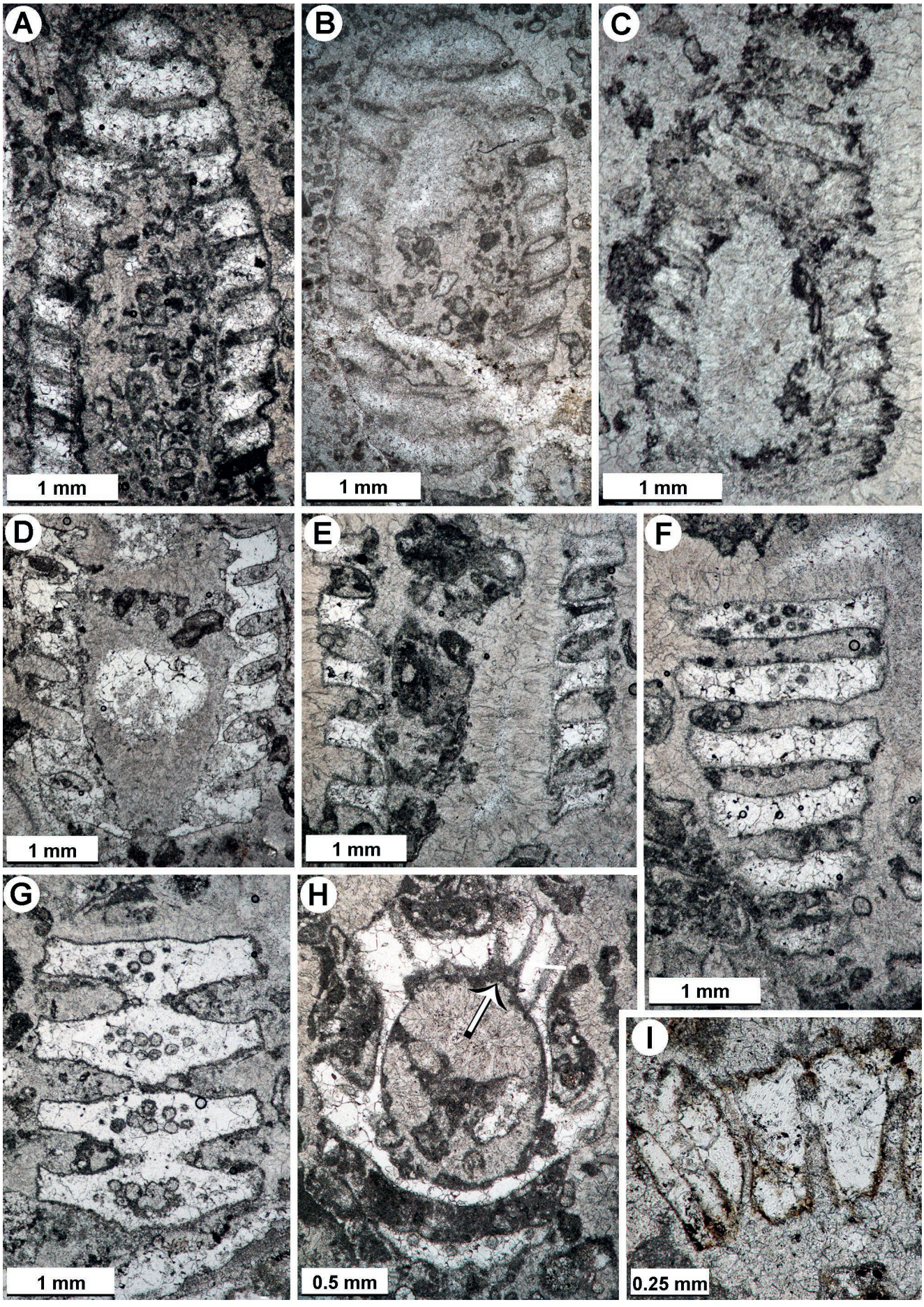
D (external diameter of the skeleton) = 2.04–2.94 (mean = 2.43);
d = (internal diameter of the skeleton) = 1.09–1.79 (mean = 1.41);
d/D = 0.53–0.61 (mean = 0.58);
l (length of the laterals) = 0.41–0.63 (mean = 0.53);
h (distance between verticils) = 0.38–0.62 (mean = 0.49);
Thickness of a ring = 0.22–0.38 (mean = 0.28).

The possible synonymy between *D. annulatissima* and *Kantia monregalensis* Baretti, 1919 was questioned by Herak (1957). This author (Herak, 1957, p. 49) states: "A comparison of some published figures of *Kantia monregalensis* (Baretti, 1919, fig. 6) with those of the type specimens of *Diplopora annulatissima* (Pia, 1920, plate 4, figs 12–14) leaves no doubts that they are the same species." But further on at the same page, Herak (1957) writes: "If *Kantia monregalensis* had been validly published, the name of the species would now be *Diplopora monregalensis* (Baretti) as the name *Kantia* has been rejected. This is impossible, however, because heterogenous specimens were figured under the name *Kantia monregalensis*, and the description does not correspond to specimens that are now regarded as true representatives of the species in question. The present authors must therefore retain the name *Diplopora annulatissima*". The genus *Kantia*, rejected by Pia (1920), was re-introduced by Güvenc (1979) together with emendation of the genus *Diplopora*. The species assigned to the genus *Kantia* are characterized by vesiculiform laterals, while the species assigned to the genus *Diplopora* have trichophorous laterals. A third category of species, ascribed by some authors to the genus *Diplopora* characterized by phloiophorous laterals (e.g., *Diplopora proba* Pia, 1935), has been transferred to the genus *Pseudodiplopora* (Bucur and Enos, 2001). It is noteworthy that illustrations provided by Baretti (1919) are schematic drawings. A serious comparison between *Kantia monregalensis* and *Diplopora annulatissima* based on these illustrations is actually impossible because the laterals' shape is not visible in these schematic representations. Moreover, as Barreti assigned the alga to the genus *Kantia*, the authors have to suppose that the laterals were vesiculiform. In fact, Baretti (1919, p. 280) noted: "I pori… sono ingrossati notevolmente nella parte esterna (The pores… are enlarged significantly on the outside…)". Consequently, the present authors believe that the synonymy between *Diplopora annulatissima* and *Kantia monregalensis* (Granier and Grgasović, 2000) is not appropriate.

Another problem related to *Diplopora annulatissima* is its possible sysnonymy with *Favoporella annulata*, which was stated by Ott (1972) and subsequently accepted by Grgasović and Sokač (2003). These authors considered that *D. annulatissima* and *F. annulata* represent two forms of the same alga, but with a different degree of calcification. Bucur and Enos (2001, p. 324) rejected this synonymy on the basis of the different shape of the laterals: trichophorous in *D. annulatissima* and phloiophorous in *F. annulata*. In comparison of the two algae, two problems arise:

1. It is not clear if the arrangement of the laterals in *Favoporella annulata* is of metaspondyle type. Pictures provided by Sokač (1968), including his figure 1 with the alga reconstruction, rather show that the laterals do not start from the same insertion point of the main stem and accordingly it is not a metaspondyle alga. Besides, Sokač (1968, p. 210) noted this feature in the diagnosis of the species *F. annulata*: "The branches with the widened bases depart separately from the main stem…". On the contrary, *D. annulatissima* has a metaspondyle arrangement (see for instance Bucur and Enos, 2001, plate 3, fig. 13; Kotański, 2013, plate 27, fig. 6, plate 28, fig. 1). This characteristic would differentiate both algae. But if the arrangement of the laterals in *F. annulata* proves to be metaspondyle, and we accept that *D. annulatissima* and *F. annulata* represent two forms with a different degree of calcification of the same alga, than this alga must be assigned to the genus *Pseudodiplopora* (phloiophorous laterals with metaspondyle arrangement, Bucur and Enos, 2001) in the new combination *Pseudodiplopora annulatissima*. To resolve this issue, the careful study of well-preserved

Fig. 4. *Diplopora annulatissima* Pia, 1920. All specimens from Farska Kolonia. **A–D.** Longitudinal oblique (A, C, D) and oblique (B) sections. Note in C the external enlargement of the laterals (*Favoporella*-type laterals). A – thin section FaK4/952, B – thin section FaK4/954, C – thin section FaK/959, D – thin section FaK/961. **E.** Longitudinal section. Thin section FaK5/960. **F, G.** Tangential sections. F – thin section FaK5/960, G – thin section FaK5/961. **H.** Oblique section showing the shape of the laterals and their metaspondyle arrangement (arrow). Thin section FaK5/964. **I.** Fragment of transverse section showing the shape of the laterals. Thin section FaK4/953.


A
1 mm
B
1 mm
C
1 mm
D
1 mm
E
1 mm
F
1 mm
G
1 mm
H
0.5 mm
I
0.25 mm

specimens of *Favoporella annulata* is necessary, to see if the alga is metaspondyle or not.

2. It is noteworthy that Kotański (2013) raised the issue of possible synonymy between *D. annulatissima* and *Gyroporella cylindrica* Gümbel, 1872, but he also emphasized the necessity to formally conserve the name *D. annulatissima*.

Diplopora annulata (Schafhäutl, 1853) Schafhäutl, 1863
Fig. 5A–C

1853 *Nullipora annulata* n. sp. – Schafhäutl, plate 6, fig. 1a–f.

1863 *Diplopora annulata* n. gen, n. comb. – Schafhäutl, p. 324, plate 65e, fig. 6a, b.

2000 *Diplopora annulata* (Schafhäutl, 1853) 1863 – Granier et Grgasović, p. 32. [With extended synonymy.]

Remarks: Rare specimens belonging to this species were found in thin sections with frequent *Diplopora annulatissima*.

Family TRIPLOPORELLACEAE (Pia, 1920)
Berger et Kaever, 1992
Genus *Salpingoporella* (Pia, 1918)
emend. Carras *et al*., 2006
Salpingoporella cf. *krupkaensis* Kotański, 2013
Fig. 5D–K

2013 *Salpingoporella krupkaensis* n. sp. – Kotański, p. 50, plate 1–4.

Remarks: *Salpingoporella krupkaensis* was described by Kotański (2013, p. 50) as having "…Branches (tubercles) weakly attached to the wall of the central cavity, rapidly extended distally and froming funnel-like tubercles (plate 1, fig. 7) merging with the adjacent rock, where they begin to touch, forming probably a rarely and poorly preserved cortex (plate 2, fig. 4) absent from Jurassic and Cretaceous species (Kamptner, 1958, p. 110)". Kotański (2013) also remarked that *S. krupkaensis* is the oldest species of the genus *Salpingoporella*. However, he considered *S. krupkaensis* as "…the only Triassic species of *Macroporella sensu lato* with consequently euspondyle whorls…" (Kotański, 2013, p. 51), leading thus to a confusion between *Macroporella* and *Salpingoporella*. He did not compare *S. krupkaensis* with other Triassic, Jurassic or Cretaceous *Salpingoporella*, but with *Kantia comelicana*, an alga with a metaspondyle arrangement of vesiculiform laterals. Two comments should be made in connection with these remarks of Kotański: 1) by its euspondyle arrangement of laterals, *Salpingoporella* differs essentially from *Macroporella*, the two genera belonging to two different families of dasycladalean algae: euspondyle Triploporellaceae and aspondyle Seletonellaceae, respectively; 2) in contrast to the statement of Kamptner (1958, p. 110), all species of *Salpingoporella* are supposed to have an external cortex (see emended diagnosis of the genus *Salpingoporella* in Carras *et al*., 2006, p. 458).

Kotański (2013) gives no dimensions for his new species, considering it an unimportant feature. However, dimensions could be considered for discriminating species in some cases (cf. Bassoullet *et al*., 1977, p. 159). The authors measured the dimensions of the specimens illustrated by Kotański (2013), using the magnification in his photos. As emphasized in Table 1, the specimens from the material of the authors are smaller, hence the incertitude regarding the identity of the two algae. Six species of *Salpingoporella* are known from Upper Triassic deposits worldwide (cf. Schlagintweit *et al.*, 2001; Carras *et al.*, 2006): *Salpingoporella spectabilis* (Bystrický, 1962), *S. humilis* (Bystrický, 1967) *S. sturi* (Bystrický, 1967), *S.*? *tibetica* Flügel and Mu, 1982, *S. triasica* Richter *et al.*, 1999, and *S. austriaca* Schlagintweit *et al.*, 2001. By its dimensions, *S.* cf. *krupkaensis* is closer to *S. triasica* Richter *et al.*, but it differs from the latter by its larger mean values of the main parameters, by the much larger laterals (larger pores), and by the thicker calcareous wall. *S. austriaca* is even smaller and has closely set verticils of conical laterals. All other Triassic *Salpingoporella* differ from *S.* cf. *krupkaensis* by their overall larger dimensions.

On the basis of the dimensions, which do not overlap in any parameter, the present authors deduce that *S. krupkaensis* Kotański, 2013 and *S.* cf. *krupkaensis* are two different species. However, taking into account their close morphological similarity, the authors prefer to ascribe the identified specimens, with some reservations to *Salpingoporella krupkaensis*.

Table 1

Comparison between the general dimensions of *Salpingoporella krupkaensis* Kotański, 2013 and *Salpingoporella* cf. *krupkaensis* described in this paper

	Salpingoporella krupkaensis Kotański, 2013	*Salpingoporella* cf. *krupkaensis* (this paper)
L (max. obs.)	5.83	2.69
D	1.00–1.27	0.44–0.72 (mean = 0.58)
d	0.50–0.66	0.18–0.50 (mean = 0.29)
h	0.17–0.22	0.24
l	0.19–0.22	0.09–0.18 (mean = 0.14)
p (distal)	–	0.09–0.14 (mean = 0.12)
w	–	8–9

Genus *Physoporella* Steinmann, 1903 emend.
Grgasović, 1995
Physoporella prisca Pia, 1912
Fig. 6A–G

non 1912 *Oligoporella prisca* mihi – Pia, p. 42, plate 5(4), figs 2, 4, 6, 8.

1926 *Diplopora elegans* n. sp. – Assmann, p. 505. [Nomen nudum, type not illustrated.]

1931 *Oligoporella elegans* Assmann – Pia, p. 273, plate 21, figs 3–6.

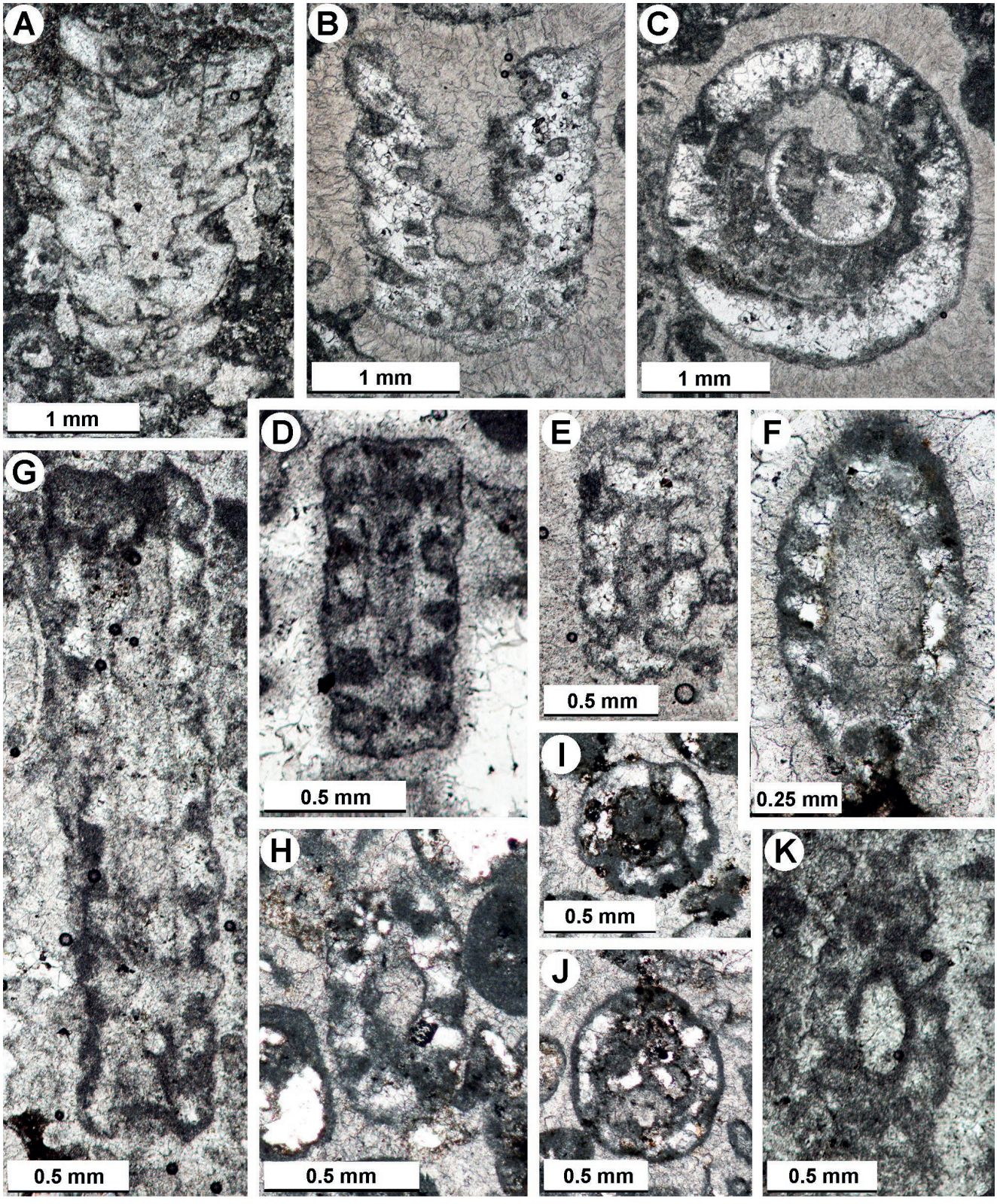


Fig. 5. Dasycladalean algae. **A–C.** *Diplopora annulata* (Schafhäutl, 1853) in longitudinal-oblique section (A), oblique-tangential section (B), and transverse section (C). Farska Kolonia. A – thin section FaK5/962, B, C – thin section FaK5/960. **D–K.** *Salpingoporella* cf. *krupkaensis* Kotański, 2013 in longitudinal-oblique section (D), oblique sections (E, F, H, K), longitudinal section (G), and transverse sections (I, J). D, E, G – Farska Kolonia, thin section FaK5/960, F, H, I, J – Tarnów Opolski, thin section TOp/oolity, K – Strzelce Opolskie, thin section SO1/101.

2000 *Oligoporella elegans* Assmann ex Pia 1931. [= *Diplopora elegans* Assmann 1926, nomen nudum – Granier et Grgasović, p. 111, with synonymy.]

2000 *Oligoporella prisca* Pia 1912 – Granier et Grgasović, p. 119. [with synonymy.]

2013 *Oligoporella elegans* Assmann ex Pia 1931a – Kotański, p. 52, text-fig. 2, plates 5–7.

Remarks: Validating the species *Oligoporella elegans* Assmann 1926, Pia (1931, p. 273) noted (translated from German): "*Oligoporella elegans* is very close to *O. prisca*. The Alpine species has larger mean dimensions, so that the smaller specimens reach the dimensions of the German specimens. The internal cavity is smaller in *Oligoporella prisca* (with respect to D) and the verticils are closer. In general, they can be very numerous. The occasional enlargement of the pores towards the exterior is present in both species. It is better, however, to keep both species separate, at least until localities with mixed specimens will be found". In its revision of the genera *Physoporella* and *Oligoporella,* Grgasović (1995) synonymized the species *O. elegans* and *O. prisca*, with the latter species as senior synonym being assigned to the emended genus *Physoporella*.

Kotański (2013) gives the following dimensions of *Physoporella prisca* (sub *Oligoporella elegans*): D = 0.58––1.0 mm; d = 0.27–0.64 mm; D/d = 46–63%; h = 0.2 mm. The dimensions we measured on the specimens studied in this paper are:

D = 0.34–0.90 (mean = 0.65) mm;
d = 0.17-0.54 (mean = 0.37) mm;
D/d = 46.6–66.6%;
h = 0.17–0.45 (mean = 0.31) mm.

Physoporella cf. *pauciforata* (Gümbel, 1972) Steinmann, 1903
Fig. 6H–O

1872 *Gyroporella pauciforata* n. sp. – Gümbel, p. 274, plate D3, fig. 2a–e.

1903 *Physoporella pauciforata* (Gümbel) nov. comb. – Steinmann, p. 50.

2000 *Physoporella pauciforata* (Gümbel 1872) Steinmann, 1903 – Granier et Grgasović, p. 130 (with extended synonymy).

Remarks: Together with *Physoporella prisca* we found specimens which are morphologically similar to *Physoporella pauciforata*, but of smaller dimensions:

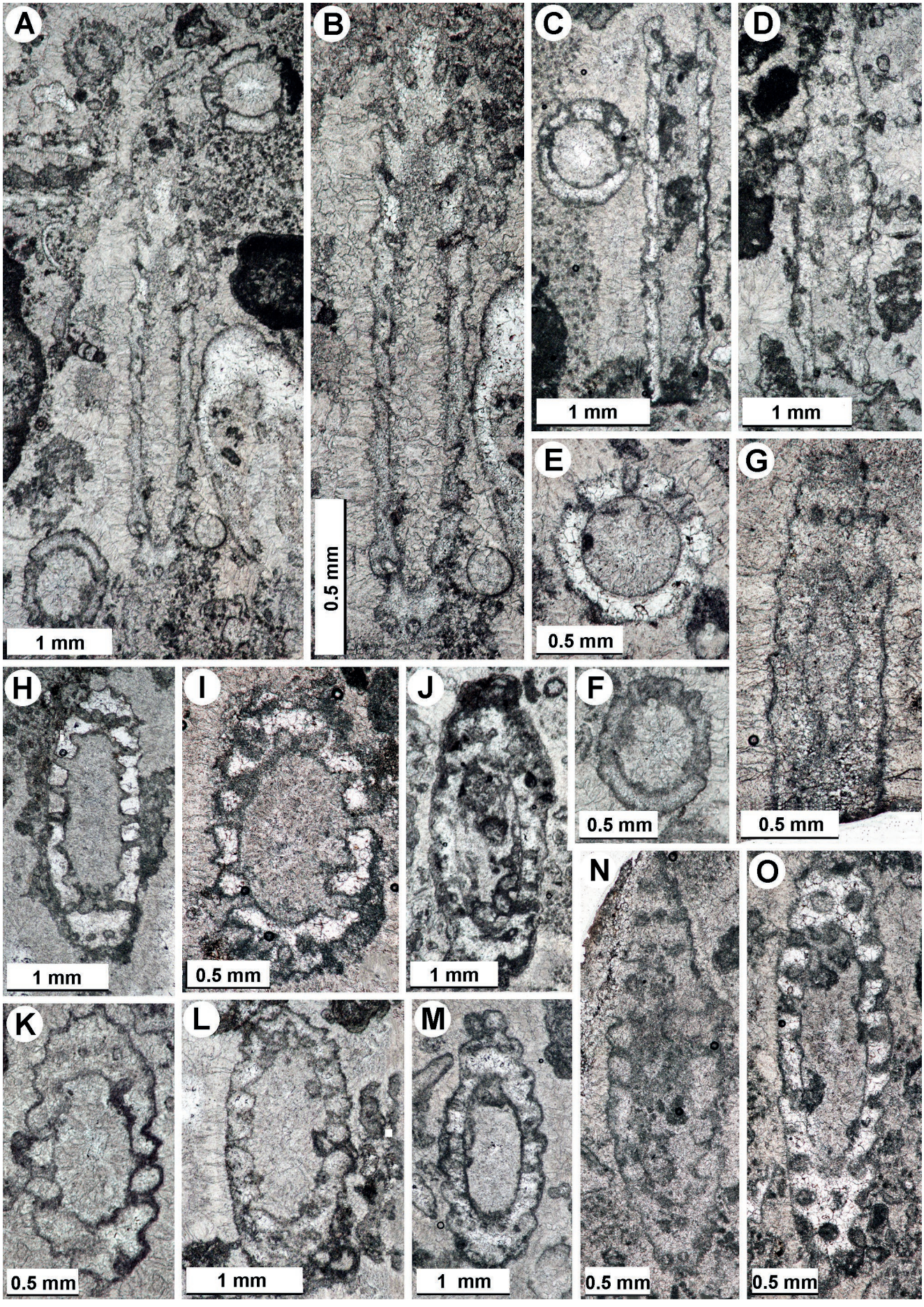
D = 0.84–1.27 (mean = 1.02) mm;
d = 0.40–0.91 (mean = 0.61) mm;
h = 0.28–0.32 (mean = 0.29) mm.

Physoporella pauciforata typically has larger dimensions (e.g., Gümbel, 1872; Bystrický, 1964; Schlagintweit *et al.*, 2003).

Genus *Holosporella* Pia, 1930
Holosporella? sp. 1
Figs 7A–C, 8A, B

Remarks: A single thin section from Farska Kolonia provided numerous specimens of spheroidal-ovoidal bodies, sometimes presenting a small peduncle. They have a thin, micritic, unperforated wall. Elliott (1958) described from the Upper Triassic of Iraq such spherical bodies as a new problematic fossil, *Lacrymorphus perplexus*, and emphasized that some of the specimens have a pear, acorn or retort shape. Further species of *Lacrymorphus* have been described from Cretaceous strata by Radoičić (1967) as *Lacrymorphus catenaeformis* and *Lacrymorphus globosus*. The first one was subsequently transferred to the genus *Humiella* Sokač and Velić, 1981 (Masse *et al.*, 1984). Similar microfossils were illustrated by Pecorini (1972) as *Lacrimorphus catenaeformis* Radoičić *sardus* n. subsp. Cherchi and Schroeder (1985) revised these fossils and assigned them to the genus *Sarfatiella* Conrad and Peybernès, 1974 under the combination *Sarfatiella sarda*. Subsequently, *Sarfatiella* became a junior synonym of the genus *Holosporella* Pia, 1930. Following Masse *et al*. (1984), the two genera are differentiated by the presence (in *Humiella*) or absence (in *Sarfatiella* [= *Holosporella*]) of perforations in the wall of ampoule-like laterals. It is worth mentioning that pores in the calcareous coating of dasycladales also have been noted in *Kopetdagaria sphaerica* Maslov by Bucur (2002) and in *Actinoporella podolica* by Granier (1988) and Schlagintweit and Enos (2012). Following Schlagintweit and Enos (2012), this should be a species-dependent character. Starting from these considerations, the spherical-ovoidal bodies from Upper Silesia could belong to laterals of *Holosporella*. Together with the spherical bodies we found some rare dasycladalean skeletons that preserve a calcareous wall around the central cavity, which appears to be the proximal part of laterals (Fig. 7C). It is possible that these algae bore the spherical bodies (fertile ampoules) like in the hypothetical reconstruction in Figure 8A. Another possibility is that no relationship existed between these two algae and the spherical bodies simply represent fertile ampoules of *Holosporella*, as in the hypothetical reconstruction in Figure 8B. *Holosporella*? sp. 1 differs from the Upper Triassic *Lacrymorphus perplexus* by its much larger dimensions.

Fig. 6. Dasycladalean algae. **A–G.** *Physoporella prisca* Pia, 1912. A. Longitudinal and transverse oblique sections. Thin section FaK4/954. B. Close-up view of the specimen in longitudinal section in A. C. Longitudinal and transverse sections. Thin section FaK4/952. D. Longitudinal-oblique section. Thin section FaK5/959. E. Transverse section. Thin section FaK5/960. F. Close-up view of the specimen down-left in A. G. Oblique section. Thin section FaK5/960. All specimens from Farska Kolonia. **H–O.** *Physoporella* cf. *pauciforata* (Gümbel, 1872) in oblique sections. All specimens from Farska Kolonia. H, L – thin section FaK4/962, I – thin section FaK4/950, J, N, O – thin section FaK4/952, K – thin section FaK4/951, M – thin section FaK5/960.


A
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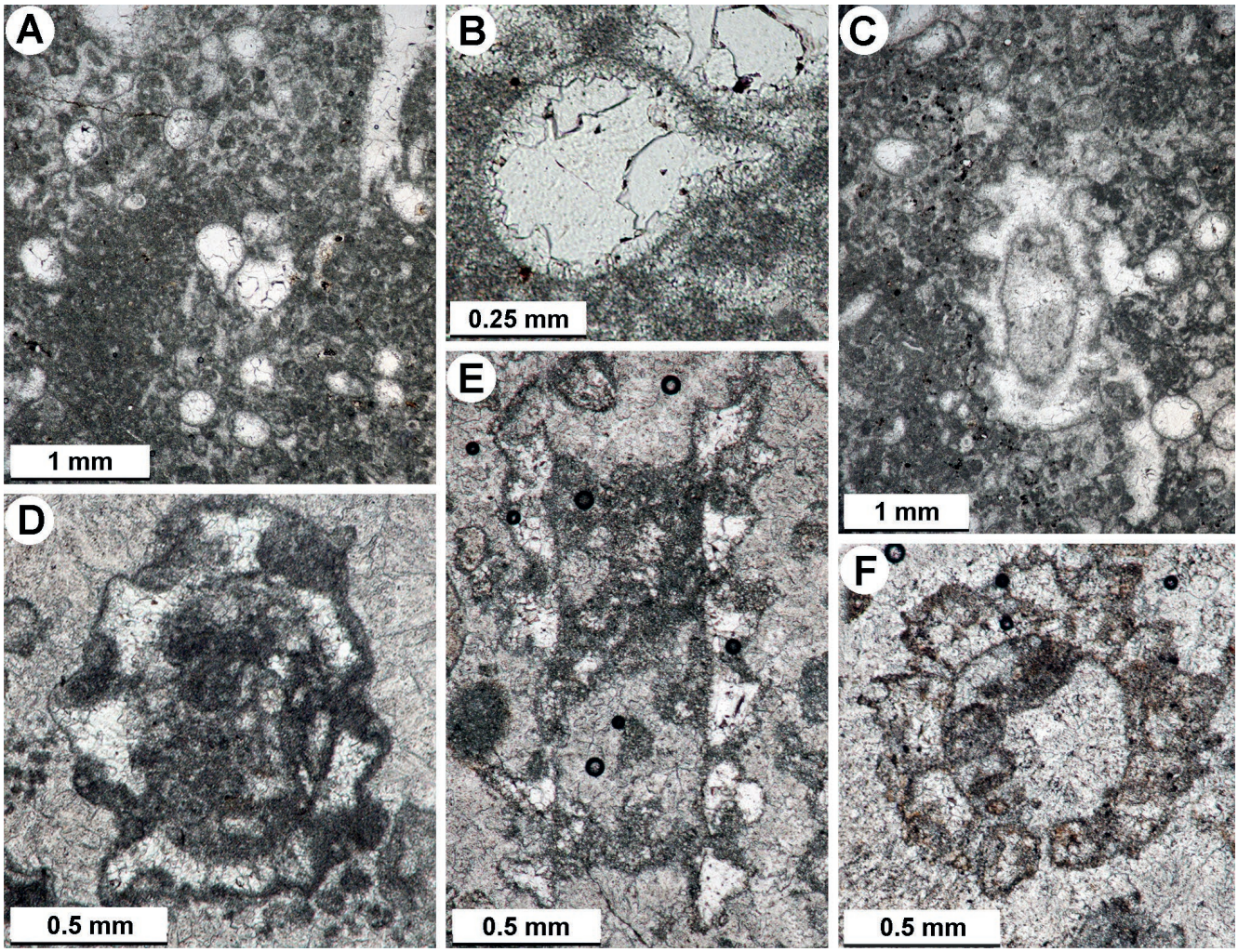

Fig. 7. Dasycladalean algae. **A–C.** *Holosporella*? sp. 1. A – spheroidal and ovoidal bodies spread in the sediment, probably representing fertile ampoules of a *Holosporella*. Thin section FaK4/949. B – close-up view of the specimen in the middle of A, showing a short peduncle. C – Dasycladalean alga associated with the spheroidal-ovoidal bodies. Thin section FaK4/949. All specimens from Farska Kolonia. **D–F.** *Holosporella*? sp. 2. in oblique section (D), longitudinal section (E), and transverse section (F). All specimens from Farska Kolonia, thin section FaK4/950.

Holosporella? sp. 2
Fig. 7D–F

Remarks: In two thin sections from Farska Kolonia, there were rare specimens of a dasycladalean alga, which probably had vesiculiform laterals. Calcification affected only the proximal part of the laterals, so that the distal part cannot be observed. Somewhat similar specimens were recently described from the Upper Triassic of North America as *Holosporella*? *rossanae* Bucur and Del Pierro (in Bucur *et al*., 2020), but the Upper Silesian specimens have slightly larger dimensions:

D = 0.86–1.14 (mean = 1.02) mm;
d = 0.50–0.64 (mean = 0.59) mm;
p = 0.19–0.24 (mean = 0.22) mm;
h = 0.31 mm.

Only three species of *Holosporella* are known from Triassic deposits: *Holosporella conradii* Barattolo *et al.*, 2008, *Holosporella magna* Bucur and Fucelli (in Bucur *et al.*, 2020), and *Holosporella*? *rossanae* Bucur and Del Pierro (in Bucur *et al.*, 2020). As mentioned before, *Holosporella*? sp. 2 from Silesia is closer to *H.*? *rossanae*, but more material is necessary to compare the two species properly.

Associated microfossils and age of the alga-bearing deposits

The calcareous algae are associated with the following benthic foraminifera (Fig. 9): *Endotriadella wirzi* (Koehn-Zaninetti, 1969) (Fig. 9A, I, J), *Earlandinita elongata* Salaj in Salaj et al., 1967 (Fig. 9B), *Endotebanella* sp. (Fig. 9C, D), *Meandrospira deformata* Salaj, 1967 (Fig. 9E), *Meandrospira dinarica* Kochansky-Devidé and Pantić (Fig. 9F–H), *Pilammina densa* Pantić (Fig. 9K), *Trochammina* cf. *alpina* Kristan-Tollmann, 1964 (Fig. 9L), *Tolypammina* sp. (Fig. 9M), and *Diplotremina astrofimbriata* Kristan-Tollmann, 1960 (Fig. 9N). The foraminiferal assemblage, along with frequent *Diplopora annulatissima*, indicates a late Anisian (Illyrian) age of the Diplopora Beds (Salaj *et al*., 1983, 1988).

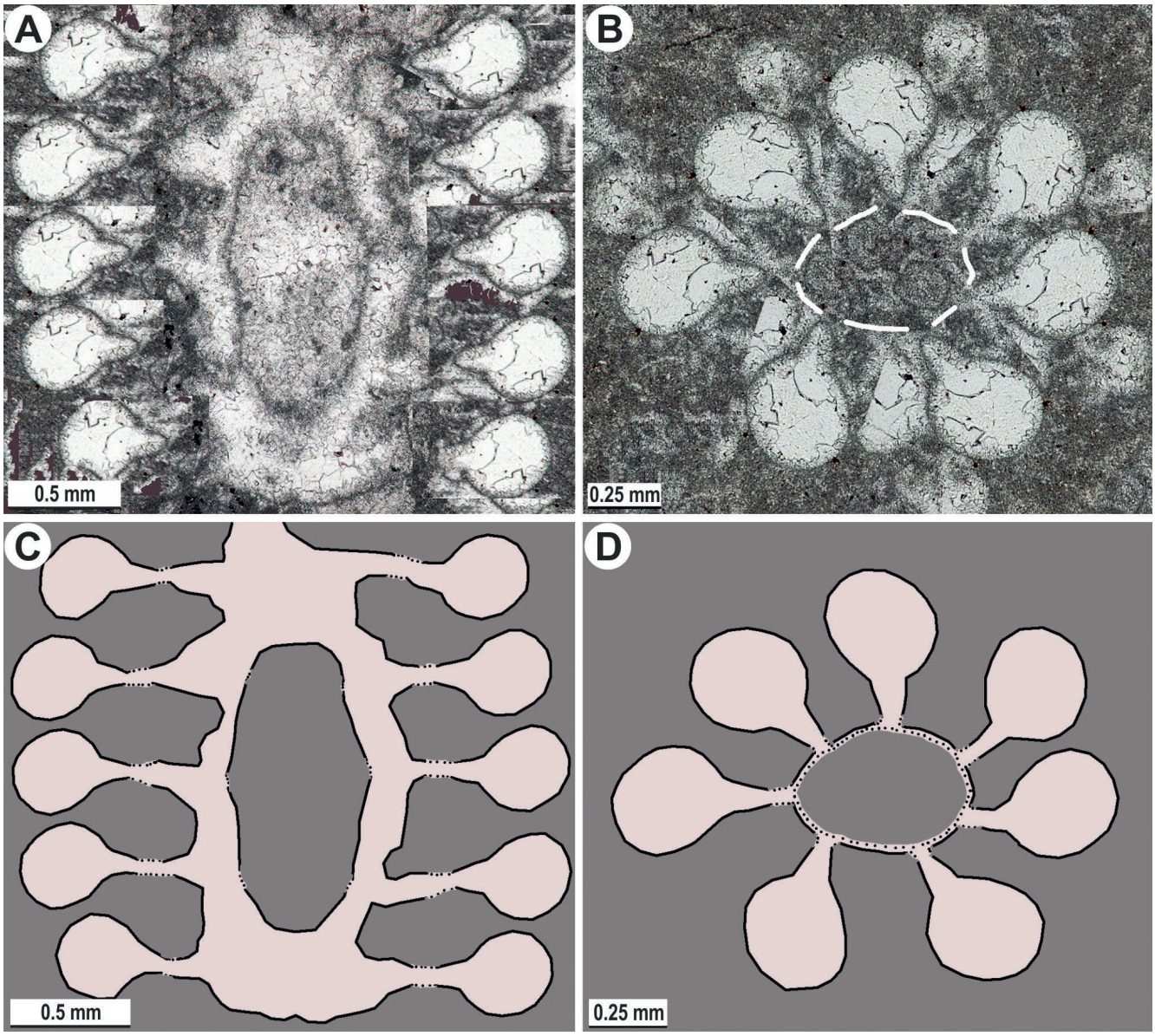

Fig. 8. Two hypothetical reconstructions of *Holosporella* sp. 1. **A.** Reconstruction based on the supposed relationship between the spherical bodies and the associated dasycladalean. The reconstruction is a photomontage, using the dasycladalean in Figure 7C and spherical body in Figure 7B. **B.** Alternative reconstruction showing the arrangement of the fertile ampoules around a non-calcified main stem. The reconstruction is a photomontage, using the spherical body in Figure 7B. **C.** Schematic drawing of A. **D.** Schematic drawing of B.

CONCLUSIONS

The Middle Triassic carbonate deposits of the south-eastern Germanic Basin (Upper Silesia) contain in their upper part (so-called Diplopora Beds) numerous specimens of dasycladalean algae. The algae were studied extensively by Kotański (2013) on weathered material. The supplementary study by the present authors on relatively well-preserved specimens from undolomitized strata revealed seven species and allowed the revision of their systematic position. The present authors consider *Diplopora anulatissima* Pia, 1920 and *Favoporella annulata* Sokač, 1968 as two different species, at least until the metaspondyle arrangement of the laterals in *Favoporella* will be proven. *Oligoporella elegans* Assmann ex Pia, 1931 is considered a junior synonym of *Oligoporella prisca* Pia, 1912 and is transferred to the genus *Physoporella* Steinmann, 1903, emend. Grgasović, 1995. Some of the dasycladalean algae described here (*Salpingoporella* cf. *krupkaensis*, *Holosporella*? sp. 1, and *Holosporella*? sp. 2) could represent new species, but more well-preserved material is necessary to decide in this respect.

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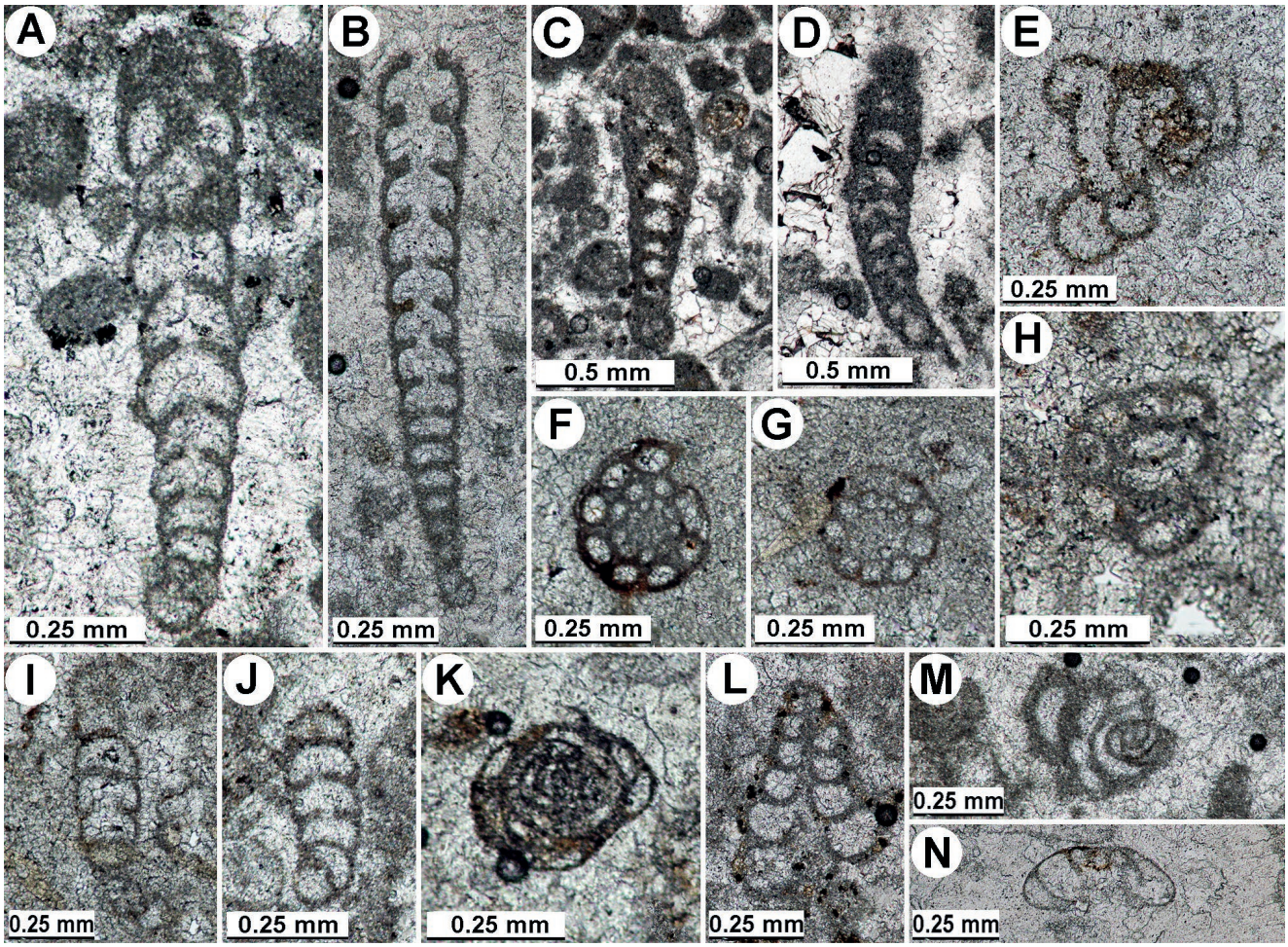

Fig. 9. Foraminifera associated with dasycladalean algae. **A, I, J.** *Endotriadella wirzi* Koehn-Zaninetti, 1969. Tarnów Opolski, thin section TOp/576–577. **B.** *Earlandinita elongata* Salaj, 1967. Farska Kolonia, thin section FaK4/952. **C, D.** *Endotebanella* sp. C – Strzelce Opolskie, thin section SO4/326; D – Tarnów Opolski, thin section Top10/algi. **E.** *Meandrospira deformata* Salaj, 1967. Farska Kolonia, thin section FaK4/953. **F–H.** *Meandrospira dinarica* Kochanski-Devidé & Pantić, 1966. Libiąż, thin section Li8. **K.** *Pilammina densa* Pantić, 1965. Farska Kolonia, thin section FaK4/953. **L.** *Trochammina* cf. *alpina* Kristan-Tollmann, 1964. Farska Kolonia, thin section FaK4/956. **M.** *Tolypammina* sp. Farska Kolonia, thin section FaK4/952. **N.** *Diplotremmina astrofimbriata* Kristan-Tollmann, 1960. Farska Kolonia, thin section FaK4/954.

a subject in depth. Reviewers Felix Schlagintweit and Jochen Kuss are thanked for critical and valuable comments on the manuscript.

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Appendix

GPS coordinates of all outcrops presented in this study (in alphabetical order)

Dąbrowa Górnicza – "Ząbkowice" active quarry (50º22′19″N, 19º17′54″E)
Farska Kolonia – five small inactive quarries (50º32′18″N, 18º16′53″E; 50º32′09″N, 18º16′50″E; 50º32′16″N, 18º16′15″E; 50º31′52″N, 18º16′36″E; 50º32′09″N, 18º16′40″E)
Jaroszowiec – "Stare Gliny" active quarry (50º21′05″N, 19º35′22″E)
Kamień Śląski – active quarry (50º33′31″N, 18º07′53″E)
Libiąż – active quarry (50º06′51″N, 19º20′04″E)
Nowa Wioska – "GZD" active quarry (50º30′01″N, 19º12′40″E)
Nowa Wioska – "PROMAG" active quarry (50º30′35″N, 19º14′02″E)
Nowa Wioska – "TRIBAG" active quarry (50º30′05″N, 19º14′16″E)
Przełajka – not existing quarry (50º22′33″N, 19º03′09″E)
Strzelce Opolskie – active quarry (50º31′44″N, 19º18′43″E)
Tarnów Opolski – active quarry (50º33′11″N, 18º05′34″E)